# THE NEW MILLENNIUM PROGRAM'S MARS MICROPROBE MISSION


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## ABSTRACT

The second dee[)-space advanced technology validation mission in NASA's New Millennium Program will demonstrate planetary micropenetrator technologies. Two microprobes, each consisting of a very low-mass aeroshell and penetrator system, are planned to launch in January 1999 and arrive at Mars in December, 1999. The '2 kg probes ballistically enter the martian atmosphere and passive.ly orient themselves to meet peak heating and impact requirements. Upon impacting the martian surface, the probes will punch through the entry aeroshell and separate into a fore and aftbody system. The forebody will reach a depth of 0.5 to ?. meters, while the aftbody will remain on the surface for communications. Each penetrator system includes a suite of highly miniaturized components needed for future micropenetrator networks: primary baUcl-its, power electronics, control and data handling microelectronics, telecommunications equipment, an ante.nna, and a science payload package. This paper will summarize key features of the microprobe mission and system design, as well as discuss the technologies proposed for flight.


## INTRODUCTION

The Mars Microprobe Mission is the second in a series of New Millennium Program (NMP) deep space missions. The goal of the NMP is to revolutionize NASA's space programs to achieve exciting and frequent missions in the 21st Century through:

- Developing and validating revolutionary technologies.
- Reducing development times and life cycle mission costs,
- Enabling highly capable and agile spacecraft, and
- Promoting nationwide teaming and coordination.

In particular, the objective for the Mars Microprobe Mission is 10 demonstrate key technologies which will enable future network science missions. Networks have been identified as essential to understanding dynamic planetary systems. Examples include a network of pressure sensors to determine atmospheric dynamics, and a network of seismic stations to solve for interior structure.

'1'0 demonstrate network technologies, the Microprobe Project will develop two probes for deployment at Mars. Upon arrival at the planet, the probes will acquire engineering data during entry, operate, the probe payload, and relay engineering and science data to an orbiting spacecraft after impact.

Each probe flight system will demonstrate a non-ablative single-stage atmospheric entry, highly integrated microelectronics which can withstand both low temperatures and high decelerations, and in-situ subsurface science instruments, In addition, this mission will provide an opportunity to capture meaningful science data.

Technologies approved for this flight have been selected from ongoing nationwide technology programs. These technologies are being developed for flight in partnership with government agencits, industry, nonprofit organizations and academic institutions. The purpose of the NMP is to validate these technologies so that future science missions can plan for their use. without assuming the risks and full costs associated with their development and first flight.

## ACCOMMODA TION CONSTRAINTS

Due (o the unique nature of this mission, the Microprobe Project is subject to various external mission constraints as described below:

First, the probes have been given a "conditional payload status" to launch onboard the 1998 Mars Surveyor Lander spacecraft in Januar y 1999. Prior to launch, a "go / no go" decision for launch will be given subject to the Mars 1998 Lander's ability to accommodate the additional probe system mass. To minimize the impact on the 1998 Mars Lander, the following agreements have been made:

1) Two pr Obcs will be mounted on tbc Lander stack in a balanced configuration (lo minimize the impact to the Lander if the probes arc not launcbc.et),
2) There will be no electrical inter faces bet ween t he probes and the Lander flight system, anti
3) The probes wil l not require spin stabilization upon release.

Second, the Microprobe Project is currently in negotiations with the Mars Global Surveyor Project to relay data from the probes to earth via the Mars Global Surveyor (MGS) Spacecr aft. MGS, which launches for Mars in November, 1996, includes a Mars Relay (MR) communication system which is currently planned to be used to relay tbc 1998 Mars Lander spacecraft data. Thus the probes must be designed to be both compatible with unique MR communication features, and non-interfering with 1998 Mars Lander data return.

## M1SS1ON OVERVIEW

### Launch and Cruise

The 1998 Mars Surveyor Lander spacecr aft will be launched on a McDonnell Douglas Med-Lite (Delta It 7325 configuration) during a 20 day launch period which spans December 1998 / January .1999. The Lander's type 2 trajectory wilt result in arrival at the red planet approximately 11 months later in December 1999 with a target of 71° S latitude. The arrival parameters are designed to target the martian Polar Layered Terrain (f'LT) in spring, which is of significant scientific interest due to its role as a reservoir for water and other volatiles on Mars.

The microprobes are attached to the Lander cruise stage in a balanced configuration as shown in Figure 1. There arc no electrical interfaces with the Lander or crui SC stage, and thus there is no communication with the probes from installation on the pad until data relay after impact.

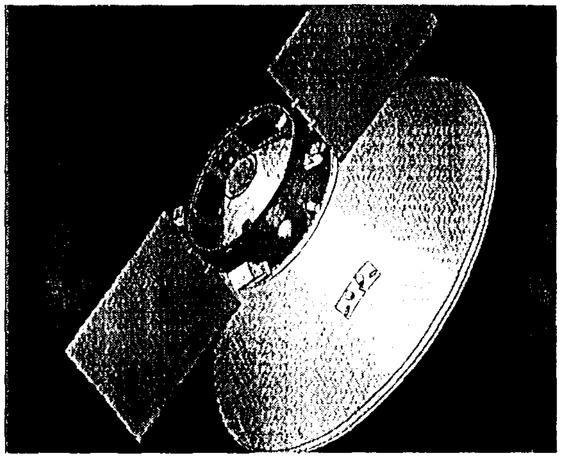


Figure 1: Cone shaped microprobe mounted on t he 1998 Mars Surveyor cruise ring; second probe is on opposite side

Upon arrival at Mars, the 1998 Mars Lander separates from its cruise ring approximately 250 seconds prior to Mars impact. The force of separ ation i nit iates mechanical pyres which in turn separate tbc probes from the cruise ring, approximately 7 seconds later. The microprobes are not spin stabilized upon release from the Lander cruise ring.

### Ent ry, Descent and Landing (EDL)

Because the microprobes have no active control, attitude determination, propulsive system, or spin stabilization, tbcy will have a random or ientation and possibly a small initial tumble rate. After leaving the cruise stage (approximately 110 km above the surface), the

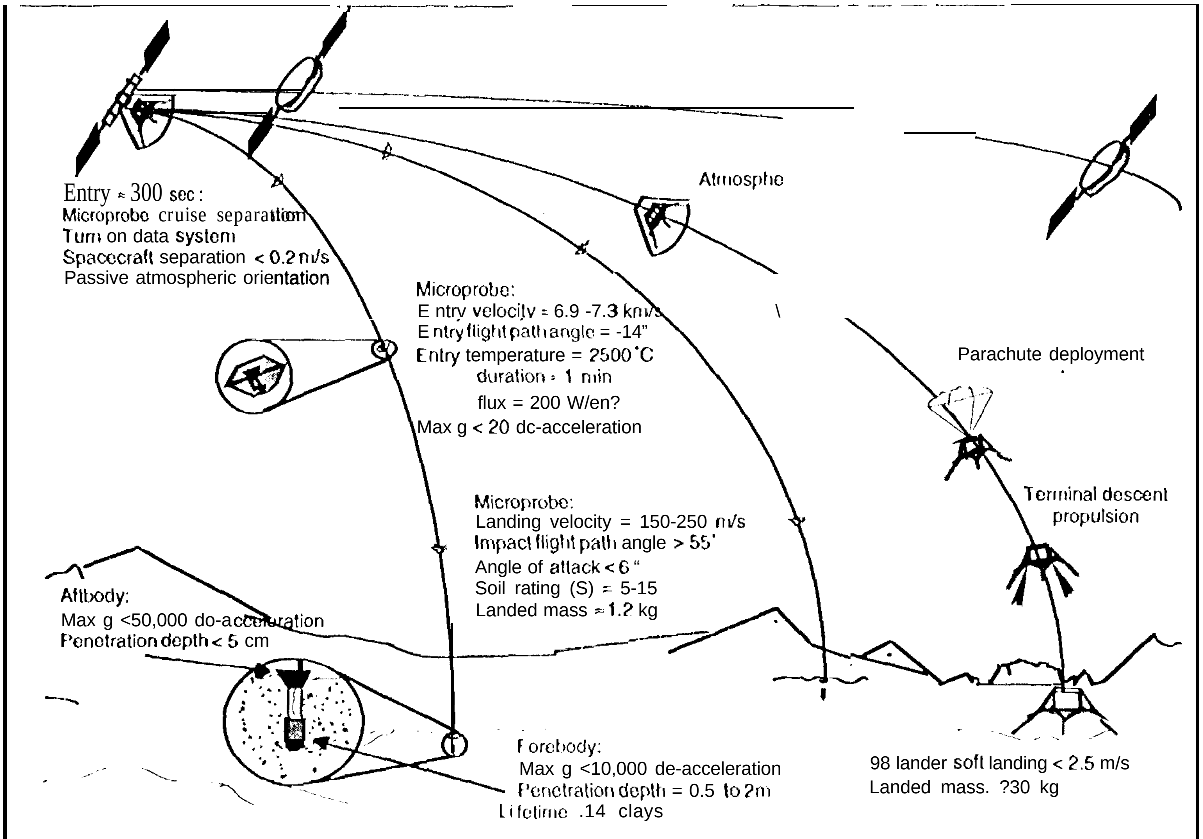



**Figure 2: Microprobe Entry, Descent and Landing Scenario**

microprobes will passively orient themselves to meet both heating and impact requirements.

The microprobe EDL system is single stage from atmospheric entry until impact. The non-ablative aeroshell has the thermal capacity to withstand the heat of entry (300 W/cm²) without material destruction, thus providing a significant mass advantage over traditional aeroshell designs. The aeroshell will be carried to the surface, and will shatter upon impact leaving the penetrator aftbody clear for communications with the MGS spacecraft.

The microprobes are expected to hit the surface with an impact velocity of 150 to 250 m/s, an impact flight path angle > 55°, and an angle of attack < 6°. Upon impact, the penetrator will separate into a fore and aftbody that are connected via a cable system. The forebody is expected to penetrate to a depth of 0.5 to 2 m for soil types that vary from frozen-soil to very 100 SC" fine-grained soil, respectively. It must also withstand a peak rigid body shock of up to 10,000 g's. The aftbody is designed to penetrate to a depth of up **to 5 cm,** and withstand a peak rigid body shock of < 80,000 g's.

An illustration of the microprobe EDL phase is given in Figure 2.

## Operations

The forebody of the micropenetrator will include a microcontroller, power electronics, at least 3 accelerometers, a subsurface sampling/water detection experiment and at least 2 temperature transducers. The forebody will weigh less than 900 g, and its isothermal temperature may range from 0 to -110° C depending on the thermal inertia of the soil at the landing site.

The aftbody will include lithium batteries, a microtelecommunications system including an antenna, a meteorological pressure sensor, and conductive fins for radiative heating of the

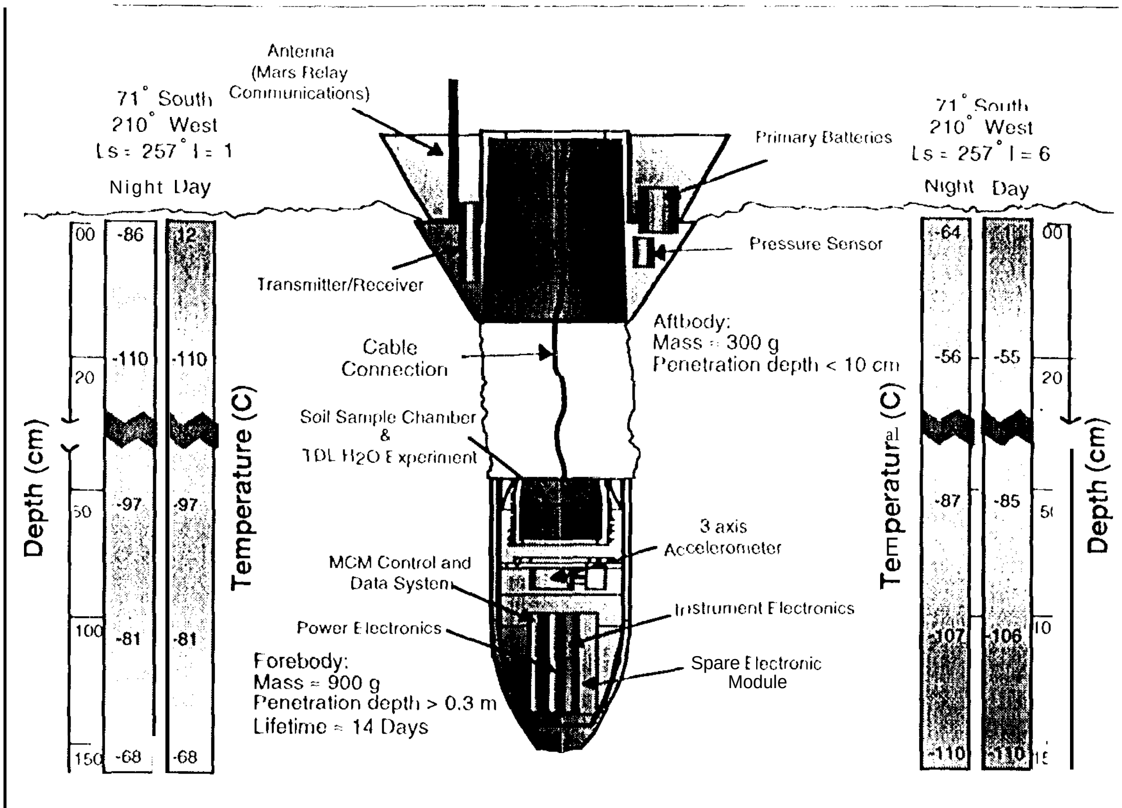



**Figure 3: On-orbit Operational Timeline**

batteries. The aftbody will weigh less than 400 g, and its temperature will range from +10 to -85° C over one martian day. An overview of the post- impact probe con figuration is given in Figure 3.

Upon impact, the deceleration force of the probe will deploy a UHF antenna and radiative fins on the aftbody. Soil will also fall into the rear of the forebody and be captured in a collection chamber. A checkout procedure will then be performed for verification of probe health.

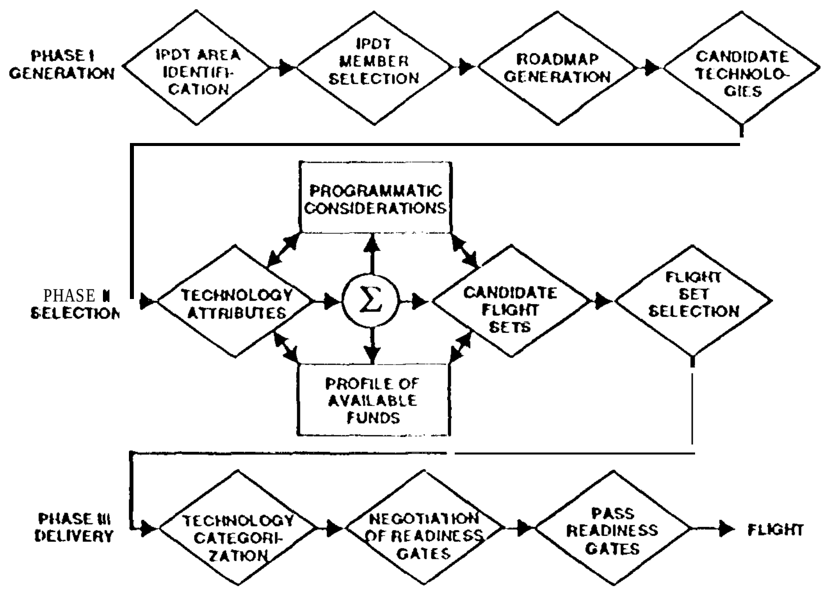
To minimize peak power requirements, the sampling/water detection experiment will be performed within 30 minutes after impact, while the forebody is still warm from atmospheric entry. This experiment is designed to characterize subsurface soil composition by measuring the temperature at which water is released. This is accomplished by slowly heating a 100 mg soil sample in 10° C increments, and measuring water vapor content using a Tunable Diode Laser (TDL). Data collected will be filtered and stored in the microcontroller for multiple transmissions back to earth.

The probe will also collect temperature and pressure measurements every hour for the entire primary mission phase, which is the first two sols. Collection of these measurements will continue through a tentative secondary mission phase which will continue until the probe battery is depleted (approximately 12 additional days). The aftbody pressure sensor will provide meteorological data. Two temperature sensors mounted at opposite ends of the forebody will provide both soil conductance information and engineering status.

Data transmissions to the orbiting spacecraft are planned to take place 4 times during the first two sols, and once a week thereafter. Each UHF transmission session relays approximately 64 Kbytes of data at an approximate 7 Kbit/s rate.

The spacecraft batteries are designed to operate at least 50 hours and, as a goal, up to 2 weeks in the extreme martian thermal environment. This assumes a 2 W peak power for the one time 20 minute execution of the sampling/water detection experiment, a 0.5 W peak power for each data

Figure 4: NMP Technology Selection Process




lownlink, and a 1 to 2 mW quiescent power for non-operating modes.

## TECHNOLOGY SELECTION PROCESS and MANAGEMENT APPROACH

The NMP organization includes Integrated Product Development Teams (IPDTs) which are comprised of technology experts from industry, academia, NASA and other government centers. The six NMP IPDTs are listed below:

- Autonomy
- Microelectronic Systems
- Instrument Technologies and Architectures
- In situ Instruments and Microelectromechanical Systems (MEMS)
- Communication Systems
- Modular and Multifunctional Systems

Each IPDT has established a "roadmap", or phased technology development plan, which defines the current state of the technology, the technological goals for the 21 st century, and milestones to achieve those technological goals.

For each NMP demonstration flight, IPDTs recommend specific technologies for flight validation. Each technology is then given a value for its long-term impact on science return and cost, the degree to which it is revolutionary in nature, and the risk reduction offered by flight validation. The Program Office, with inputs from the Flight Team, Science Working Group (SWG) and Science Advisory Team (SAT), then considers the total value of different combinations of proposed technologies along with the science value for that flight.

Programmatic and fiscal issues are also considered by the. Program Office before. a flight technology set is recommended to NASA Headquarters for approval.

After a technology is selected for flight, three "Sate.s" are negotiated between the. IPDT and the Flight Team which ensure timely delivery of that technology for flight. The three gate.s which must be pawed for flight acceptance are given below:

| | |
|---|---|
| Gate 1 | Technology Readiness Review |
| Gate 2 | Key technology hardware/software demonstration |
| Gate 3 | System hardware/software demonstration |

The management approach for each technology is dependent on the consequence of that technology failing to pass a readiness gate. For the purposes of describing this approach, each technology is assigned a category ranking as shown in Table 1.

Table 1: Technology Categories

| Category | Role of Technology | Consequence of Failure to Pass Gale |
|---|---|---|
| I | Essential | Postpone or redefine mission |
| II | Fundamental | Substitute state-of-the-art technology |
| III | Enhancing | Fly without the technology |

Category I technologies are given full flight team management oversight including status updates. Category II technologies are given minimal flight team supervision, with the (Ilrcc-gale schedule set to ensure that adequate time and resources are available to substitute. an existing technology if necessary. Category III technologies arc also given minimal flight team supervision, with the ttucc-gale schedule set to ensure the technology is delivered for spacecraft integration and test only.

An overview of (he. NM]' technology selection process is given in Figure 4.

## FLIGHT TECHNOLOGIES

This section describes the technologies selected and approved for flight by NASA Headquarters for the Mars Microprobe Mission. It also dc.scribes why each technology is exciting for 21st century science.

### Non-Ablative Single-Stage Entry Aeroshell

The microprobe will employ a single-slagc-to penetration entry system with no deployables, stages, active control or propulsion. This system will self-orient itself upon atmospheric entry prior to peak heating. The aeroshell will be made of a non-ablative heat shield material; possible candidates include a refractory metal silicon carbide or carbon-carbon, An inside layer of carbon foam will provide additional thermal protection to keep the aft and forebody cool. The 700 g aeroshell system will be designed to shatter upon impact.

Using a non-ablative material represents a mass savings of 50% or more over conventional thermal protection system technologies. It also minimizes aerothermal and aerodynamic analyses. Designing a passive re-orientation system simplifies the attachment and deployment strategy with the 1998 Mars Lander Spacecraft.

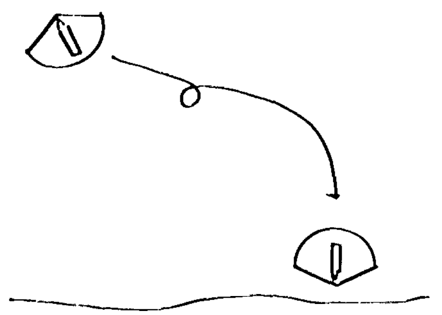


Figure 5: Passive Re-orientation System

### Telecommunications Microsubsystem with Programmable Transceiver

The probe telecommunications system will include a programmable transceiver. This development is exciting because of its multimission capability, which can be used for any moderate rate/range relay for both earth and space applications. The transceiver programmability extends to the data rate ( 1 bps to 5(JO kbps), the modulation format (FSK or PSK), and the receive/transmit frequency (380 to 480 MHz). The microsubsystem represents a 100x reduction in mass over current spacecraft telecommunications subsystems (< 10 gm), and occupies a very small volume (< 8 cm3)

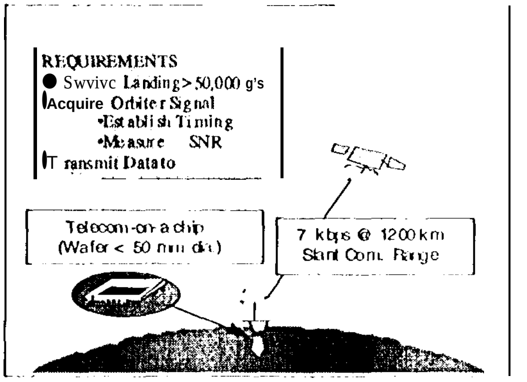



Figure 6: Microtelecom munications Concept

### Power Microelectronics: Mixed Digital and Analog ASICs

The microprobe power control, regulation, and distribution will be operated via microelectronics that use mixed digital/analog ASICs. Mixed digital/analog ASICs represent an exciting extension of the miniaturization achieved by the digital electronics industry in the last quarter century. This power system will use CMOS technology with very low temperature capabilities. This technology is useful for a suite of applications including any high density sensor, instrument, or assembly.

Microcontroller

The microprobes will include an 8051-based data acquisition and control system with modest data processing capability. This microcontroller is an **8 bit** processor with 64K RAM and 128K EEPROM. The system is designed for both very low power (< 50 mW at 1MHz, 1 mW sleep mode) and small volume and mass (< 8 cc, 30-90 g). The microcontroller system will also include an internal 12-bit 16 channel analog to digital converter (ADC). Because this system has multifunctional applications, it will be developed and funded by a consortium of government and industry participants. Potential applications for this microcontroller include any small system or instrument including microprobes, actuators, and health and status monitors.

Ultra Low Temperature Lithium Primary Battery

Probably the most challenging aspect of the microprobe design is the requirement to survive the severe martian thermal environment. With help from conductive aftbody fins, the batteries are likely to stay no warmer than -60° C. To survive this extreme, both lithium-thionyl chloride and lithium-carbon monofluoride battery chemistries are being considered. The microprobe primary battery will be designed for a 6-12 V range and a 3 year shelf life. The battery will also have to withstand a worst case 80,000 g rigid body shock environment.

Low temperature battery technology is extremely useful for Mars landers and rovers as well as other deep space missions. It also has commercial, DOD, and DOE applications.

Flexible Interconnects for System Cabling

The microprobe's high shock and vibration environment presents a challenge for system-level packaging. One packaging approach that will be demonstrated on this mission is flexible interconnects for system-level cabling. Flex is a Kapton based multilayer circuit carrier and interconnect technology. The flex circuits used for the penetrator will include electrical interconnects between Kapton layers which are formed with a patented anisotropic bonding material made of thermal glue matrix with embedded solder balls. This bonding technique can withstand temperature extremes and can be used to attach surface mount parts using reflow solder. This approach provides unparalleled bending flexibility and oxidation resistance, and is applicable to any micro sensor, assembly, or instrument.

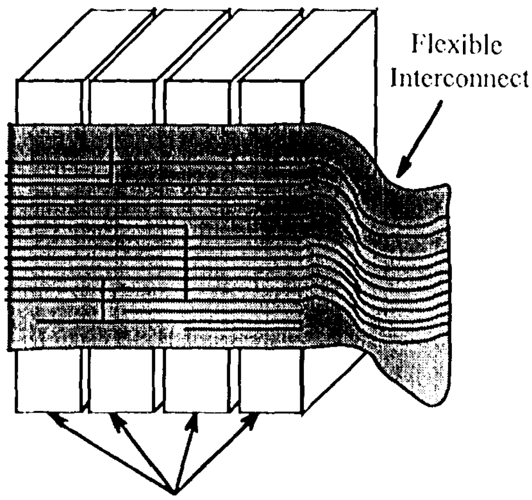



Figure 7: Flexible Interconnect for System Cabling

Subsurface Sampling/Water Detection Experiment

A subsurface sampling/water detection instrument has been chosen as the primary science instrument for the microprobes. The primary purpose of this instrument is to demonstrate subsurface sampling capability. This sampling is accomplished as soil falls passively into the back end of the forebody and into a small collection chamber upon impact. The secondary purpose of this experiment is to detect ice and/or absorbed water in the soil collected, with a goal of identifying hydrated minerals. This is accomplished by increasing the temperature of the sample in a stepwise fashion and measuring the water detected and sample temperature at each step. Water detection is accomplished via a micro Tunable Diode Laser (TDL) spectrometer.

Including this instrument on the Microprobe Mission demonstrates penetrator-based subsurface sample collection and geochemistry capability. This experiment can be extended in future missions to include quantitative analysis of water and other volatiles, which addresses high science priorities for Mars and other planets.

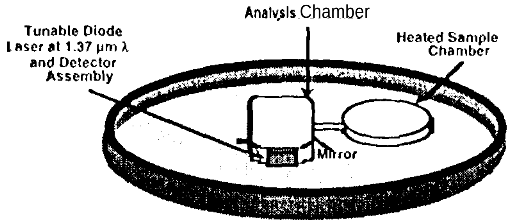



Figure 8: Subsurface Sanlpliag/Wafer Detection Instrument

Meteorological High-g Micropressure Sensor

As an important step toward validating a microprobe meteorological network, this mission will include a pressure sensor on the probe aftbody. Demonstrating a meteorological network is of primary science interest for Mare, Venus and Titan.

A silicon capacitive micromechanical pressure transducer will be used in conjunction with a miniaturized hybrid/high-g electronic package.. The ?0 gm sensor will measure an absolute pressure range of O - 12 mbar over an operating range of -120° C to + 50° C.

Thermal Properties High-g Temperature Sensor

Two temperature sensors will be mounted al opposite ends of the penetrator forebody to determine soil conductivity from the penetrator cooling curve after impact. This experiment validates a mass and power efficient approach to determining thermal properties over traditional methods, in that the surrounding soil does not need 10 be heated to obtain a temperature vs. time profile. This experiment also represents an initial step towards a planetary heat flow experiment which is of scientific interest for determining the thermal evolution of the planets.

Accelerometers

Although penetrator accelerometers are not a "new technology" per se, the application of accelerometers and penetrators for deep space missions has not been demonstrated (o date. At least three piezoresistive or piezoelectric accelerometers will be mounted in the Mars microprobes and will serve two purposes, First, accelerometer data will provide verification of martian soil penetration, and characterizes entry conditions (e.g. depth of penetration and acceleration at impact) for technology validations. Second, the accelerometers will provide information regarding geological stratification; possibly including the depth 10 an ice layer that is predicted to occur near the surface and will provide information on climate changes on Mars.

## SUMMARY

'l'he, New Millennium's Mars Microprobe Mission provides an exciting demonstration of a suite of new technologies for deep space penetrator networks. Networks have been identified as a key scientific objective for the exploration of dynamic planetary systems. Technologies selected for flight will be developed by a team of JPL, industry, academic and other government agency participants. As part of the New Millennium Program, the Mars Microprobe Project will also explore new management and engineering approaches toward developing inexpensive, rapid development, planetary space.c! aft,

## ACKNOWLEDGMENTS

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